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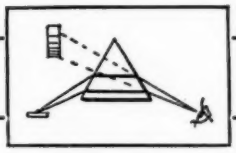

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1935

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Journal of the
OPTICAL SOCIETY *of* AMERICA

VOLUME 25 MARCH, 1935 NUMBER 3

The Transmission of Ultraviolet Radiation Through Chinese Window Papers

CH'EN SHANG-YI, *The National Academy of Peiping Institute of Physics Research*
AND
MENG CHAO-YING AND WILLIAM BAND, *Yenching University, Department of Physics*
(Received November 28, 1934)

Both sector photometer and microphotometer analyses were carried out on the Hg spectrum transmitted by papers popularly used as window materials in Chinese homes. The intensity distribution of transmitted radiation, after normal incidence, through samples of twelve different kinds of paper has been studied, and the total transmission calculated for various wavelengths. The total transmission of visible light (4354A) ranges from 38 percent to 72 percent, and of ultraviolet light (2967A) from 16 percent to 41 percent for the papers studied. Oiling the papers with vegetable oil ("tung yu") increases the transmission by about 50 percent, at the same time narrowing the distribution curve and strengthening the paper against the effects of moisture.

INTRODUCTION

NO quantitative analysis of the transmission through window papers has so far been made, but it is known that qualitatively, anti-scorbutic radiation is transmitted in appreciable intensity. The fact that there is apparently less rickets among oriental children than among occidental children has been explained as due in part to the almost universal use of paper windows in oriental homes, although the oriental fashion in children's clothes has probably more significance.

Nevertheless the importance of a quantitative spectral analysis of the transmission through window papers in use by three hundred million people is sufficiently manifest to need no emphasis. The remarkably high percentage total ultraviolet transmission through popular window papers discovered in the present work has already suggested to local medical institutions the use of such window materials in their tuberculosis clinics; owing to the high cost of ultraviolet transmitting glasses manufactured in the west, paper permits a very great economy.

APPARATUS AND PROCEDURE

A Cooper Hewitt Labarc supplied the constant intensity Hg spectrum; it was carefully regulated and its constancy checked at regular intervals.

The spectrum was photographed in a Hilger E-3 quartz spectrograph which gave at once the whole range of wavelengths to be studied. The plates were developed in metol-hydroquinone.

A Hilger sector-photometer was used for one set of analyses, and a Moll Type A microphotometer of Kipp for an independent set. The sector photometer method was used only as a check on the normal transmitted rays.

Eight neutral screens of densities from 0.383 to 2.21 were made according to Harrison's method.[1] Their densities were found directly

[1] Harrison, J. O. S. A. **18**, 492 (1929).

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from microphotometer analysis, by the sector photometer and also by comparison with other standard screens.

For sector-photometer work the paper was mounted in front of one sector and a suitable screen in front of the other. For microphotometer work the paper specimen was mounted on a square diaphragm close in front of a quartz lens. The Labarc was at the focal point of this lens. The whole of this system was mounted on a rotating table so that the paper specimen contained the axis of rotation.

One spherical and one cylindrical quartz lens produced a slit shaped image of the illuminated part of the paper falling entirely inside the slit of the spectrograph. The time of the exposure was governed by a photographic shutter fitted before the spectrograph slit. The equipment was set up in a dark room and all stray light screened from the spectrograph slit.

Each exposure (see Fig. 1) included spectra through five standard screens to permit independent determination of the straight portion of the characteristic curve of each plate.

To estimate the total transmission through the scattering paper, sample spectra were taken for a series of orientations of each paper spaced at 10° intervals on both sides of the normal, maintaining the incident beam normal to the paper. If I_0 be the intensity of the direct beam as measured when the paper specimen is removed, and $X_i \cdot I_0$ the intensity measured through the paper set at angle i to the axis of the collimator, D the diameter of the fixed convex lens which collects the scattered radiation, and R the distance from the paper to this lens, since all the light in the solid angle subtended by the lens D at the paper (distance R) enters the spectroscope slit, the total transmission intensity will be given by the integral:

$$\int (2\pi R \cos i R di X_i I_0)/(\pi D^2/4) = (8R^2/D^2) I_0 \int X_i d(\sin i).$$

The value of this integral is found from the graph of X_i against sin i, the areas being obtained by a planimeter; the results are expressed as percentages of I_0.

FIG. 1. Spectra for microphotometer analysis (Fen-lien Paper).

1. Screen S-4
2. " S-4+B
3. " S-5
4. " S-6
5. " S-7
6. Paper at 90°
7. " " 80°
8. Paper at 70°
9. " " 60°
10. " " 50°
11. " " 40°
12. " " 30°
13. " " 20°
14. " " 10°

RESULTS AND DISCUSSION

Several repeated determinations of the transmission through identical samples showed errors less than 5 percent, which is the limit usually expected in the present kind of work. Repetition on different samples of the same kind of paper showed variations of the same order, indicating reasonable uniformity of the paper. The precision was greatest for wavelengths between 3347 and 2547A where the intensity was of the optimum value for the photometry. The visible lines between 4354 and 3665A were transmitted with too high an intensity to give the same precision. Low intensity radiation such as that scattered in directions more than about 10° or 20° from the normal, had to be estimated by extrapolation from the densest standard screen, but even here the precision is probably better than 10 percent.

The numerical results are given in the diagrams, Figs. 2–6. Of the four papers chosen as representative, and shown in Figs. 2 and 3, "Paila" paper is a medium weight tissue, unsuitable for window material from the mechanical point of view. The other three are all popular window papers, white and unglazed. The mechanical characteristics of these papers are given in Table I.

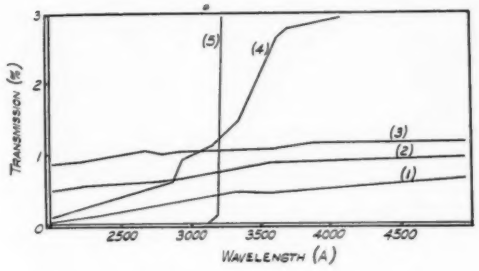


FIG. 2. Normally scattered transmission curves:
1. Fenlien Paper
2. Ping Fenlien Paper
3. Shuang-er-pa Paper
4. Paila Paper
5. Glass

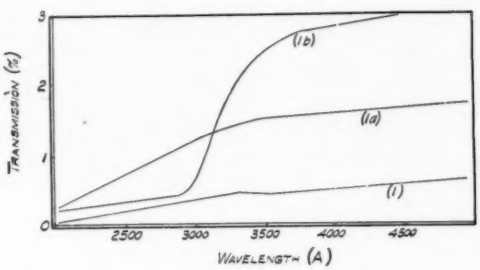


FIG. 4. Normally scattered transmission curves:
1. Fenlien Paper, untreated
1a. ditto treated with Tung oil
1b. ditto treated with Yü oil

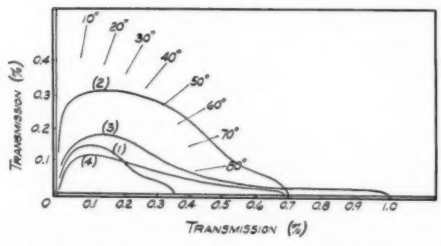


FIG. 3. Angle scattering, 2967A. Shows on polar chart intensity of scattering at all angles for the same four papers as numbered in Fig. 3.

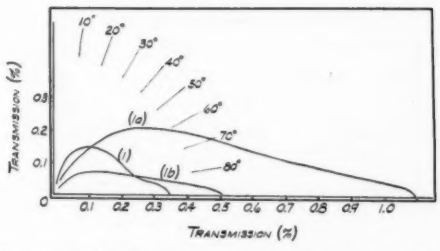


FIG. 5. Angle scattering, 2967A. Shows effect of oiling on angular scattering, the same papers as numbered on Fig. 4.

TABLE I.

Paper	Ultraviolet % 2967A	Visible % 3500A	Thickness (mm)	Density (g/cc)	Strength (kg/5cm)
Fenlien	16.4	24.0	.064	.556	4.
Ping Fenlien	41.3	53.5	.058	.523	3.5
Shuang-er-pa	22.3	25.5	.081	.311	2.
Paila	17.1	34.2	.029	.967	4.

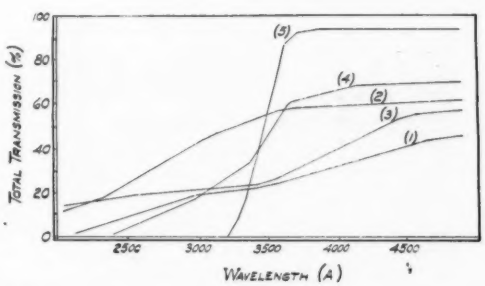
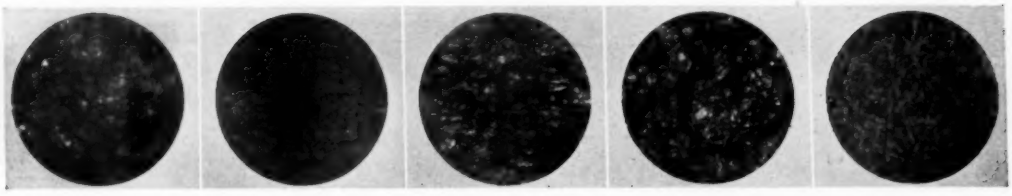


FIG. 6. Total transmitted curves. Shows total integrated transmission for all directions of scattering:
1. Fenlien Paper
2. Ping Fenlien Paper
3. Shuang-er-pa Paper
4. Paila Paper
5. Glass.

The effect of oiling with two different kinds of oil is illustrated in Figs. 4 and 5. The most popularly used oil always increases the ultraviolet transmission; it is a vegetable oil and is known to transmit ultraviolet radiation.[2] The other oil is a mineral oil, and increases only the visible transmission; in both cases it is the normal scattering that is increased, the intensity-angle curves becoming sharper.

The mechanism of transmission through papers evidently includes several possible processes. (A) Direct transmission through holes in the paper: this would be indicated where the transmission-wavelength curve was flat, since a hole will not selectively absorb ultraviolet radiation and any diffraction scattering would be greater in the longer waves. Also there would be less angle scattering for a paper containing a larger percentage of holes. The differences between the curves for the three window papers in Figs. 2

[2] This was found true for thin films of oil only, in tests carried out here.



1 2 3 4 5

FIG. 7. Microscopic photographs of paper samples:

1. Fen Lien Paper
2. Oiled Fen Lien Paper
3. Ping Fenlien Paper
4. Shuang-er-pa Paper
5. Paila Paper

Diameter of circle 1 mm.

and 3 may be in part explained by their differences in porosity as shown in the microscopic views (transmitted light) given in Fig. 7. (B) Scattered transmission through pores will also take place with similar wavelength characteristics to those of direct transmission, but the scattering will result in wide angle emergence on both sides of the paper. (C) Transmission through the cellulose fibers is probably responsible for the greater absorption in the ultraviolet part of the spectrum, although it is known that cellulose does transmit ultraviolet.[3] Papers such as "Paila" paper do not have pores or holes, and all the transmission must be through the cellulose material of which it is composed.

[3] W. W. Coblentz, R. Stair and C. W. Schoffstall, *Ultraviolet Transmission through Fabrics*, Bur. Standards J. Research **1**, 106 (1928).

The results of oiling paper can easily be explained. In the first place the oil, by capillary action, smooths down the tiny projecting hairs on the surface of the paper and so decreases the scattered reflection of the incident beam. But the oil fills the pores of the paper and so modifies the light transmitted through these pores in accordance with the characteristics of the oil. Thus except where the oil absorbs selectively, the transmission will be increased.

The writers wish to thank Dr. Tsi-ze Ny, Director of the Peiping Institute of Physics Research, for his very generous permission to use his microphotometer, and to express their gratefulness for much valuable time and help given both by Dr. Ny and Mr. S. P. Chung at the Institute.

The Influence of Present Trends in Research on the Design of Astronomical Telescopes and Accessories*

G. W. MOFFITT, *Yerkes Observatory, University of Chicago, Williams Bay, Wisconsin*

(Received December 12, 1934)

FOR some time past the members of the staff of the Yerkes Observatory have been working on the plans for a new institution to be known as the McDonald Observatory of the University of Texas. The buildings for this new observatory are now being erected on the summit of Mount Locke, in the Davis Mountains of southwestern Texas about 200 miles southeast of El Paso. The elevation is 6790 feet above sea level and the latitude is 30° 40′. The telescope will be an 82-inch reflector with Pyrex mirrors. Both the mechanical and the optical parts are now being designed and built by the Warner and Swasey Company of Cleveland, Ohio. In what follows I shall refer to this instrument as "the 82-inch."

Telescopes of great size are expensive and when once erected must be used without major changes for years to come. For this reason there is a moral obligation upon those charged with the responsibility of planning and designing, to provide wisely for the researches of the present generation of astronomers and, at the same time, to foresee the needs of the next generation as fully as possible. A most casual study of the situation would show that the building of a large one-purpose instrument would be contrary to the best interests of the science. And so the first care of any conscientious group, entrusted with the creation of a major observatory, is to see to it that the instruments are capable of serving as many of the present needs of research as possible and, as far as can be foreseen, those of the future also. In regard to this last point it is reasonable to expect at least an effort to avoid features that may hinder the work of the future. Take our largest refracting telescopes as an example. We find objectives marvelously corrected for images on the axis. But in their making no attention whatever was given to the elimination of coma. Correction on the axis was sufficient for visual work. Nevertheless coma could have been reduced and the increase in cost of these lenses would have been utterly insignificant had they been thus created with benefit of lens designing. The result would have been of almost incalculable benefit in the long series of parallax determinations made with instruments of this class.

Realizing then that there are many things to do with a large telescope those on whom the responsibility of choice rested in planning the 82-inch have not only given much study to every feature of the design themselves but they have consulted a large number of the most competent workers. The spirit of cooperation has been most gratifying. It has been comforting, too, that the viewpoints of our leading astronomers are so similar when it comes to the basic features of the design for a modern telescope. Wherever an outstanding opinion has arisen it has been explainable as the result of some special interest, and in practically every case some other solution equally suitable for the special interest, and better suited to interests in general, has been found. In fact, it was found to be possible to provide a telescope with which most of the problems of astronomical research can be effectively furthered, and in most of these fields be as effective as if it had been designed for one class of work alone. It has been possible to make full provision for work: (1) in the various phases of astronomical spectroscopy; (2) in the direct photography of faint objects; (3) in the direct photography of star fields for the determination of positions, proper motions, and stellar parallax; (4) in photometry in many of its forms; (5) in the study of double stars both by photography and by visual methods. These headings take in nearly all research activities profitably pursued at present with the aid of large telescopes.

THE CHOICE OF A MAIN MIRROR

The outstanding aberration of the paraboloidal mirror of large relative aperture is coma. The

* Presented by invitation at the meeting of the Optical Society of America in Washington, October 18–20, 1934. —Ed.

demand of modern astronomy for more light grasp means mirrors of larger size. But in addition to this a larger relative aperture is demanded for the photography of faint areas, such as the nebulae. One of the first considerations, then, is the choice of a main mirror. In a paper[1] prepared for this symposium by my colleague, Dr. F. E. Ross, the considerations that have lead to the choice of F/3.3 for the 200-inch California Institute of Technology mirror, and of F/4 for the 82-inch McDonald mirror will be clearly set forth. He shows that with mirrors of these characteristics about ninety percent of the direct photography of faint objects can be done more efficiently than with any other form of mirror system. Since Ross will discuss this matter I shall now pass on to other things, pausing just long enough to say that the advent of the Ross coma correctors a few years ago has entirely changed the situation regarding coma in mirrors of large relative aperture. Formerly it was thought that F/6 was the limit, but now F/4 and F/3 need cause no trouble on this account, for the corrector lenses increase the area of useful field many fold. Moreover, it is well to remember that at least ninety percent of the serious research carried on by direct photography of the kind here considered is done with very small field angles, and that no fundamental research problem demands an extensive field at the prime focus of a large reflector. The paraboloidal mirror of large relative aperture, used either with or without the Ross corrector as the case may require, gives all the field that will be needed.

Turning now to another phase of direct photography with the main mirror alone we come to the question of how the upper end of the telescope shall be arranged. Shall we use the Newtonian form for convenience, or shall we place the center of the plate on the axis of the main mirror in what is usually called the prime focus? The Newtonian form is convenient. But the loss of light and definition at the diagonal flat mirror is always objectionable. The present tendency is away from the Newtonian in favor of the prime focus in spite of the inconvenience of the latter. But in an 82-inch telescope the control of a camera in the prime focus, distant some five or six feet from the reach of the observer, becomes something of a problem. There are astronomers who hold that the prime focus camera must be used at all costs, while others maintain that a camera cannot be properly controlled from the rim of the tube. I made a study of the problem and found nothing at all alarming in the optical systems involved, and reached the conclusion that the objections arose from experience with apparatus designed without benefit of optical engineering. Therefore it was decided to place the camera at the prime focus and handle it entirely by remote control from the rim of the tube. Then, to satisfy the objectors, the construction of the upper end of the tube was so designed that a Newtonian camera may be added should anyone ever care to do so. I shall describe this camera later.

The Choice of the Cassegrain Focal Length

Turning now to the Cassegrain arrangement, we find that here is a combination that may be very well suited, as to focal length and relative aperture, to the needs of large scale photography, such as is required for the determination of proper motion and stellar parallax, and for the type of spectrograph suited to work on many of the problems of modern astrophysics. There is considerable freedom in the choice of a Cassegrain focal length, and the best choice will depend upon a knowledge of the kind of seeing to be expected at the station. Cases have been known where too long a focus was selected resulting in a tremor disk so large and diffuse that images suitable for measurement could be obtained only on a few of the best nights. With the spectrograph such a combination results in much of the light being stopped at the slit, and therefore the exposure times are needlessly long. The most complete information that can be had before the telescope is erected as to the kind of seeing to be expected at the station is almost necessary to a wise choice of Cassegrain focus. Selection of the site for the McDonald Observatory was made after reasonably complete seeing tests with devices designed for the purpose. In some quarters the efficacy of seeing tests made with instruments

[1] F. E. Ross, Publications of the Astronomical Society of the Pacific, **46**, December (1934).

of small dimensions is questioned. However, such tests are capable of giving comparative values and indicating the relative merits of a number of proposed sites, and when the instruments are checked at a number of existing observatories a good idea of the conditions at the proposed site as compared with those prevailing at existing observatories may be obtained. In this way it is fairly well known what may be expected at the new station. From these considerations the Cassegrain focal length was set at 95 feet, giving a relative aperture of F/14. This makes a very satisfactory scale for mensurational photography as well as a very useful relative aperture for much of the spectrographic work. And all of this with the added convenience of observation at the lower end of the telescope. For other types of research it is likely that the Cassegrain focus will be the favored one unless the problem demands the larger relative aperture and smaller scale of the prime focus. The Cassegrain observing station is by far the most convenient one in the dome, and for this reason will be the favored spot.

Choice of the Coudé Focus

There is need for work in astrophysics on spectra formed with instruments of dispersion higher than can be satisfactorily obtained in a spectrograph mounted on a moving base. It is very important that such problems be investigated. In the past various arrangements have been tried for forming an image of a star on the slit of a stationary spectrograph. Notable among these is the Coudé form of telescope in which the light is finally delivered along the polar axis of the equatorial mounting. In the large reflecting telescopes now in use the flat mirrors that send the light down the polar axis into the constant temperature room at its southern end have, of necessity, been so arranged that certain parts of the sky could not be covered because of interferences in the optical path. It was suggested by the writer that it might be possible to design a short hollow declination axis that would end before reaching the intersection with the polar axis, thereby making possible an arrangement of mirrors that does not cut the light from any part of the sky at which the telescope may be pointed. Mr. E. P. Burrell of the Warner and Swasey staff made a study of the problem and decided that the design was practical. Instead of the usual long and thin declination axis he will use a short hollow one and a system of roller bearings of large diameter. The equivalent focal length of the Coudé system will be 160 feet and the relative aperture F/24. I shall return to the Coudé focus in discussing the spectrographic equipment.

The Cassegrain Camera

Direct photography at the Cassegrain focus will be employed chiefly for the determination of proper motions and stellar distances by the trigonometrical method. It is foreseen also that provision should be made for some phases of planetary photography. The designing of a camera for this position has been practically completed and construction is proceeding in the instrument shop at Yerkes Observatory. Plates 8×10 inches in size will be used in Eastman plateholders modified to prevent slippage of plates during exposure, and checked for registration distance. Several years experience with the parallax camera of the Yerkes refractor has demonstrated that expensive hand-made metal plateholders are entirely unnecessary for cameras working at from F/18 to F/15 as these instruments do. Since the field of full illumination at the Cassegrain focus is 10 inches in diameter, most of the 8×10 plate will be usable, especially since there is little coma. It was decided to make the Cassegrain instruments of the McDonald telescope interchangeable with those of the Yerkes 12-inch and the 40-inch, which are already interchangeable. Rotation in position angle has been omitted in the Cassegrain camera. Practically the only reason for such rotation is to enable the observer to find a suitable star upon which to guide and to guide in a posture of comparative comfort. With the extended area commanded by the guiding eyepiece of the new camera, together with the large light grasp of the 82-inch mirror, it was thought that a suitable guiding star would always be available. To take care of the question of guiding posture it was decided to do the guiding by means of an electric motor running continuously which would

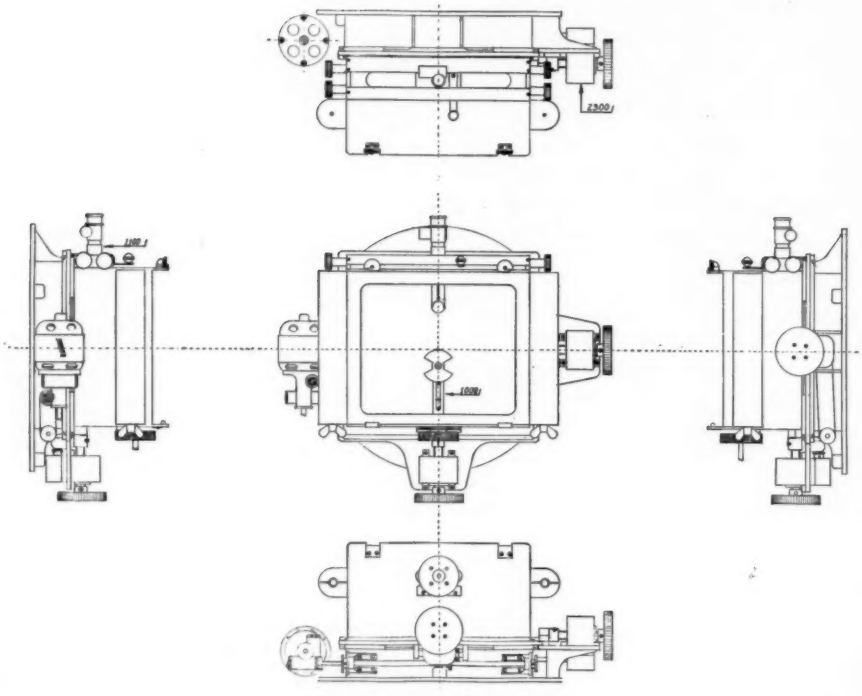


FIG. 1. The Cassegrain camera.

turn the guiding screws by means of electromagnetic clutches on the screws. With this system it is not necessary to hold the arms in cramped or uplifted positions, this being the source of most of the fatigue of guiding. The location of the guiding eyepiece is such that one may look into it without strain in any position of the telescope. The guiding screws operate cross slides, moving the rear part of the camera only. This system of guiding has been regarded as essential to the best work, for the inertia of a large telescope and its comparatively long period of free vibration render guiding in direct photography impossible with the fine motions of the telescope mounting.

In Fig. 1, from an assembly view for the use of the instrument maker, the general features of the camera are seen. The guiding eyepiece may be moved from right to left through a distance of 8 inches, and in and out a distance of $1\frac{3}{4}$ inches. It is controlled by the duplicate set of knobs at the upper corners of the camera. In work done with this camera it is sometimes desirable to reduce the apparent brightness of a star to that of a set of comparison stars. Hence the use of the rotating sector. Instead of having an adjustable sector it is much better to have a set of fixed sectors of suitable graded openings. These may be changed easily by pulling one off and slipping the stem of another into the hollow spindle of the sector drive. The sector stem and drive also have an inch of motion either up and down or from right to left of the center, thereby making it possible to arrange the field as desired. This sector is driven by means of a flexible shaft (not shown) taking power from the motor that does the guiding.

Motorized guiding was provided in this camera not because it was absolutely necessary but because we are certain that it will be better and more comfortable than hand guiding, and also because we wished to gain experience with it since in the prime focus camera it must of necessity be used. We have still retained the

hand guiding knobs which may be used at any time. In fact, it is expected that these will be used regularly in arranging the field preparatory to the exposure.

A curtain shutter will be provided so that exposures ranging from a second to a minute or two can be made with the best of guiding. For ordinary exposures of more than three minutes it suffices to use the plateholder slide as a shutter.

A frame for focusing by the knife-edge method is provided, and a large, low power scouting eyepiece can be attached like a plateholder permitting one to view all parts of the camera field during the setting-up process.

One motor, running continuously, actuates both guiding screws and the sector drive. This requires clutches on the guiding screws. We have been asked why we went to this complication. One answer is that we did not want to put three motors on the camera—one for each screw and one for the sector. But more important than this we did not want the coasting of the motor to continue to rotate the screws after the guiding buttons had been released. The clutch drums, containing two clutches each, are seen on the guiding screws adjacent to the hand knobs.

The Prime Focus Camera

Without taking time to describe the mechanical details I shall now show how we propose to arrange the prime focus camera for control from a station on the rim of the tube. A plate magazine will be put onto the camera directly from the bridge and then the observer need not touch the camera until all of the plates are exposed. All controls will be electrical by means of hidden wires that will not obstruct the light on its way to the main mirror. The guiding eyepiece can be set for the comfort of the observer and the guiding control button unit will be held in the hand while the arms may be kept in any comfortable position desired by the observer. Since this camera represents one of the advanced steps taken in the planning of the McDonald telescope I shall describe its optical features in some detail.

First of all let it be stated that the usual controls for pointing the telescope on any given star field and for handling the dome and bridge will be at the observer's hand, either on the upper end of the telescope or on the bridge. Thus it will be possible for an observer to point the telescope at will without the help of any assistant whatever. In fact, all observing operations with this telescope are to be one-man operations. Having pointed the telescope it is next necessary to inspect the entire field of view of the camera in order to see that it is arranged satisfactorily. This can be done by means of the scouting telescope placed on the control station panel on the rim of the tube (see Fig. 2). The magnifying power of this scouting glass is such that the field of view of the camera just fills the eyepiece comfortably. Three and one-half power is required with an objective of 30 mm diameter. It would thus rate as a low power night glass. It will be seen that this glass has its objective filled from every point within the camera field. It is also obvious that this glass does not utilize all the light furnished by the main mirror. This does not matter, for with it one arranges the field of view by means of the brighter stars therein. In fact the volume of light reaching the eye will be much greater than in the set-up arrangement of many large reflectors, where the unaided eye is placed far enough behind the focal plane to receive light from all points of the camera field. Here, however, it would be possible for the observer to bring his eye closer at the expense of field until he had reached the least distance for distinct vision. But even so he would still be at a disadvantage as compared to our scouting glass. Having set up the field it is next necessary to find a suitable guiding star and to bring the guiding system to bear on this star. In the new camera it will be possible to guide with a star either within the field of view of the camera or outside of it at one side of the camera. This entire field is shown in the scouting glass and the observer may at once select some star of suitable brightness within the range of motion of the guiding system. A small indicator shows the spot in the field on which the guiding system is trained and it is the work of a few moments to adjust the system by means of the electrical controls. In the designing of the guiding system the entire F/4 beam must be kept if possible, for here plenty of light is desirable. A field of view 5 mm in diameter in the focal plane was

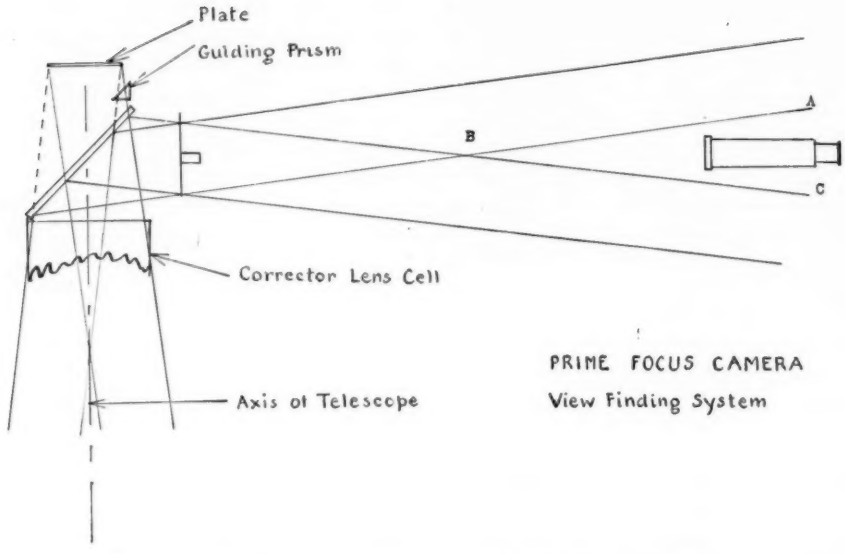


FIG. 2. The finding and setting system of the prime focus camera.

considered sufficient for finding the guide star after the set-up was completed. But after the star is on the intersection of the cross wires there is little need for field of view. One possible system may be likened to a sort of periscope in which none of the optical parts can be in the middle portions of the path through the instrument. Another possibility would be a system resembling an elongated compound microscope the objective of which would be carried on the camera and the eyepiece on the rim of the telescope tube. The latter system has been selected as it seems to be simpler and to give promise of better definition. The magnification of our cross-wire viewing system is equivalent to that obtained in viewing the focal plane directly with an eyepiece of 0.67 inch focal length.

Having brought the guiding system to bear on a suitable star the observer is ready for the exposure, assuming that the telescope was focused beforehand. Since the magazine was placed in position before beginning work, he simply throws the switch that retracts the diagonal mirror and when this has shut itself off, i.e., is completely out of the light path, he brings the guide star to the cross wire by means of the push button control held in the hand, and throws the switch that opens the electrically operated shutter. The exposure ended, the shutter is closed and the plate changed in the magazine.

Whenever long exposures are required in work of this kind it has been customary to remove the plateholder at intervals and refocus, using the knife-edge test; after which the plateholder would be returned to position and the exposing proceeded with. While all this requires careful design of the camera and plateholder it has been the standard way of doing it. With the new camera the plateholder does not have to be removed to check the focus at any time. Simply close the shutter, bring in the diagonal mirror, observe the focus, reset it if necessary, and then go on with the exposure. The optical system of the knife-edge focusing mechanism is seen in Fig. 3. In use a bright star is brought to the obscured spot in the center of the field as nearly as convenient by means of the scouting glass. One then looks into the focusing eyepiece with the focus of this glass set to show the knife-edge sharp. The star is brought to position almost grazing the knife-edge. Then the observer slides the eyepiece next to his eye to the position for focus on the image of the 82-inch mirror. By means of the fine motions of the telescope, or

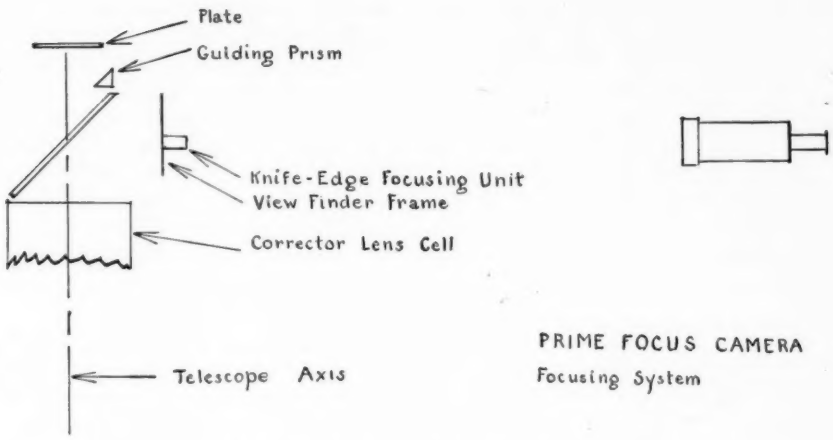


FIG. 3. The focusing system of the prime focus camera.

by a slight pressure on the telescope tube the star image is made to move over until cut off at the knife-edge, the shadow on the mirror image giving the information as to the condition of focus. When the focus has been adjusted by means of the built-in motorized focusing cage on which the camera is mounted, the field is again picked up and the exposure proceeds. Before beginning work the same method of focusing is employed. While three separate optical systems have just been described it has been found to be possible to provide only one telescope at the guiding station, this glass having three eye-pieces suitably chosen.

DRIVING SYSTEM

One of the features in telescope design about which there seems to be the greatest diversity of opinion among astronomers is the driving clock and driving train. I have studied this problem for several years past and it seems to be the fact that the diversity of opinion arises through lack of information as to just what a certain drive is actually doing, coupled with a lack of information as to what other types of drive can do. There is also the matter of the detailed design of any given type of drive. A drive of a certain type that performs as perfectly as any mechanism could possibly do in one instance has in another place been condemned and removed simply because of faulty detailing in the design. The present tendency is away from the old conical pendulum friction governor, and rightly so. For of all the mechanisms that have ever been put into telescopes as driving clocks this one is now the most faulty that could be considered. I have heard it said by a good astronomer that there is nothing quite so dependable as gravity, the inference being that since the conical pendulum is supposed to be controlled by gravity it should be the best. The theory of the *simple conical pendulum* shows how nicely the thing can be made isochronous. But the usual treatment does not take into account a number of the actual masses that must be present. As it works out in practice the device is temperamental, even in the best of designs, when compared with some of the constant speed motor mechanisms now available. I have designed several of these in various forms to replace conical pendulum drives, and in every case the new installations have brought to light certain periodicities in the driving gear trains that had never even been suspected before, owing to the irregular driving of the conical pendulum. Moreover the conical pendulum drive is the most costly to make of any to the extent of a few thousands of dollars in a large telescope (according to price quotations of one of our leading manufacturers).

There are other reasons why the conical pendulum is obsolete. A number of years ago a

drive was evolved in which an electric motor was constrained to run as a slave to a pendulum clock. This drive proved to be very dependable and uniform. It also had another advantage—its speed could be quickly changed by known and definite amounts by the simple expedient of switching to another pendulum clock having a different rate or by adding small rider weights to a pan on the pendulum of the clock. The desirability of this feature of changeable rate by known amounts arises from the fact that with the refinements of present guiding a telescope should not drive at the same rate in different parts of the sky because of the effect of atmospheric refraction and of flexure in the instrument. And now we come to the latest development—a drive that consists of an electric motor locked in step with the oscillations of a tuned electrical circuit. This has been so perfected at the McMath Observatory that one may either set a known rate or, as is actually done in guiding, adjust the rate without leaving the guiding eyepiece whenever it is seen that the rate is definitely fast or slow. In a short time the rate is thus adjusted so that further handling of the guiding screws is very much reduced and there is no drift of the image. It is a noteworthy fact that a number of astronomers have enthusiastically endorsed this system after a few hours actual guiding with it, although in some instances they were decidedly skeptical before. The McDonald telescope will be equipped with this system. In addition there will be an emergency drive consisting of a synchronous motor running on the power line—a form of drive about as good as any conical pendulum except in cases of poor frequency regulation.

The merit, or rather the lack of merit, in a drive has had considerable bearing on the guiding equipment on the various direct cameras used in astronomy, and the improvement in drive embodied in this latest development renders some of the older multiple guiding eyepiece systems unnecessary, for now the rate is so nearly correct that there need be no appreciable rotation of the plate about the guiding star, when using the double slide form of guiding. Of course we always have present in a degree in keeping with the weight and the focal length of an instrument, irregularities in the drive due to the imperfections of the gear train. It is a question whether worm wheel teeth and those of the worms, can be made so accurately that quite noticeable periodicities will not result. Even if such a desirable state of affairs could be reached there is the question as to how long it would remain so because of wear. Here again the McDonald telescope shows an improvement in that all of its gear train is enclosed in suitable dust-proof housings and proper attention has been given to the matter of adequate lubrication under all conditions of climate.

Having refined the driving mechanism to a point where it is justifiable to introduce a device for varying the rate to take care of effects of atmospheric refraction and of flexure, it is only reasonable to provide some means of taking care of the equally noticeable effects of atmospheric refraction and flexure in declination. Therefore, this telescope will have a drive in declination, the rate of which can be changed while guiding at the eyepiece by a system of controls similar to those for changing the rate in right ascension. Any or all of these refinements in drive may be used or not as the observer wills.

Astrophysics

In astrophysics the present problems, and those of the near future, involve either work on fainter objects or work with higher dispersion. For both cases more light is needed. In addition, the relative aperture of the telescope must be held within certain limits, and these limits do not agree with those that are most useful for direct photography at the prime focus. If one considers a spectrograph of suitable dispersion, and with a collimator of, say, at least one meter focal length, it is obvious that the dimensions of the prisms and lenses become prohibitive if the relative aperture is large. It is therefore necessary to reduce the relative aperture to something between F/18 and F/12 in order to be able to design a spectrograph with suitable characteristics, and this is especially true if the instrument is to be carried on the telescope. With a main mirror designed for the needs of direct photography at the prime focus, the spectrographs can be provided for very nicely at the Cassegrain focus. Fortunately this is the most convenient place to work.

There are also a number of problems in astrophysics calling for dispersion greater than can be obtained satisfactorily with a spectrograph mounted on the telescope. The light grasp of an 82-inch is sufficient for observation of quite a number of stars at this high dispersion without unduly prolonging the exposure time. Here is where the Coudé arrangement enters the picture, for with its focal length of 160 feet and relative aperture of about F/24 it can advantageously supply a large scale spectrograph on a stationary mount in the constant-temperature room. Because of the small relative aperture the prisms and lenses need not be larger than necessary for the resolving power.

While the specifications of the different spectrographs have received serious thought the actual designing will start within the month.

For coating the mirrors of the telescope we expect to use the chromium-aluminum process. Experiments have been carried on at Cornell University under a grant received by Boothroyd and Struve. Williams has developed, expressly for use in the McDonald telescope, a new method of depositing a thin coat of chromium on the glass, on top of which the aluminum is deposited. This gives a very hard and durable surface that is expected to remain serviceable for years. Not only does this do away with periodical resilvering but the reflecting power in the short wave end of the spectrum has been decidedly increased. While this speeds up direct photography, it also makes it important to use ultraviolet transmitting spectrographs. Wherever possible the optical systems of the McDonald spectrographs will be made of such materials. A whole new spectral region will thus be opened up for advantageous investigation.

Three spectrographs will be prepared within the year. Others of various characteristics will undoubtedly follow later. The three will be: (1) A two prism ultraviolet transmitting instrument for use at the Cassegrain focus. It is probable that quartz prisms will be used; (2) a high dispersion instrument for the Coudé focus. This instrument will give about 2A per mm; (3) an autocollimating grating spectrograph similar to the one we have been operating at the Perkins Observatory for the past two years. Modern technique in grating ruling has made the grating a favored dispersing unit for certain kinds of work, and the beautiful definition that our Perkins instrument gives is very promising.

With these three instruments the spectrographic program of the new station will be started. Later, we hope to have a greater variety of Cassegrain instruments and special ones, as for example, low dispersion prime focus spectrographs for work on the nebulae. We shall avoid as far as possible the practice of making instruments with interchangeable cameras and dispersing systems. Both the optical and the mechanical requirements can be met to better advantage if each instrument is planned as a complete unit. I regret that I am unable to show you the finished designs at this time, and trust that this may not be misleading in producing an erroneous impression, for without question spectroscopy is today the outstanding tool in astronomical research. In fact, spectrographic problems are to be the major work of the new observatory.

I have said very little about some important lines of work, such for example as photoelectric photometry, that will be regularly carried on, because the telescopic requirements for these activities are not different from those already considered, and their discussion here would add nothing to show how the present trends are influencing design.

And now in conclusion, I may say that it is not only the hope but the expectation as well, of those who made the surveys for location and those who determined the features of the telescope, that the new observatory will enjoy observing conditions equal to any in the country, and that astronomers will find the equipment especially easy to use.

Photographic Plates for Use in Spectroscopy and Astronomy. IV*

C. E. KENNETH MEES, *Rochester, N. Y.*

(Received January 29, 1935)

IN three former communications on this subject,[1] a description was given of the characteristics of plates developed by the Research Laboratory of the Eastman Kodak Company especially for scientific work, these plates being based on five distinct types of emulsion, which are shown in Table I.

TABLE I.

Type	Sensitivity	Contrast	Graininess
I.	High	Medium	Average
II.	Mod. high	Medium	Average
III.	Medium	High	Low
IV.	Low	Very high	Very low
V.	Low (even when sensitized)	Very high	Negligible

From the table, it will be seen that the three characteristics of each emulsion change systematically in the same direction as we pass from Type I to Type V: the sensitivity decreases, the contrast increases, and the graininess decreases. As the result of experimental work, however, it was found that this was not always the case, especially when the emulsions were sensitized to the infrared.

The most notable example of this was an emulsion which, when unsensitized, had the general characteristics of Type IV; that is, it had very high contrast, low graininess, and low sensitivity. This particular emulsion, however, exhibited a great capacity for the acquisition of sensitivity to the infrared, so that when it was sensitized with the dye which produces the Type R sensitivity, the effective sensitivity in the spectroscope was not that of a Type IV–R plate but of a Type I–R.

It seemed necessary, therefore, to find some other description than Type IV for this emulsion. This can be done conveniently by designating the emulsion by three figures—the first referring to sensitivity, the second to contrast, and the third to graininess. Thus, if this particular emulsion (when sensitized to infrared) is designated *144*, this may be taken as meaning that the emulsion has the *sensitivity of Type I* but a *contrast and graininess corresponding to Type IV*. Strictly speaking, if this nomenclature were used for the ordinary types of emulsion, the one which has hitherto been known as Type I would be known as Type 1–1–1; and so forth, but for the present such a refinement seems unnecessary. It is not impossible perhaps to make an emulsion of the Type 1–2–1, in which the sensitivity and graininess correspond to Type I and the contrast to Type II. While the new type of emulsion 144 only deserves that designation when used with infrared sensitizing and with other sensitizings should be given another type number, in practice it is more convenient to call the emulsion by the same type number whatever type of sensitizing is used with it.

Type 144 is a useful emulsion for many purposes: When unsensitized or sensitized for the green only, it has the characteristics of an ordinary Type IV emulsion. When sensitized with the panchromatic sensitizers, it has a sensitivity corresponding to Type III, with the graininess and contrast of Type IV. With the extreme red sensitizings, Types S and U, its sensitivity corresponds to Type II; and when sensitized for the infrared, it has sensitivity equal to the Type I emulsions.

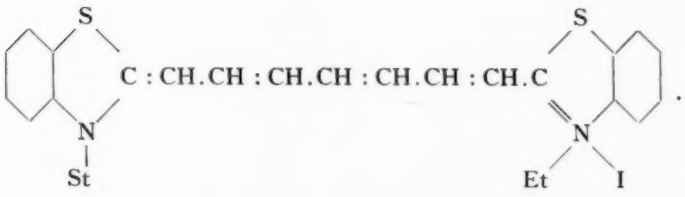
As the result of a great advance in the production of polycarbocyanine dyes by Dr. L. G. S. Brooker and Mr. G. H. Keyes,[2] it has been possible to revise and extend the sensitizing for the infrared. The sensitizers which have been used up to the present for the production of the infrared sensitive plates are dyes of the tricarbocyanine series.[3] A typical dye of this series, for instance, is 2,2′-diethylthiatricarbocyanine iodide

* Communication No. 487 from Kodak Research Laboratories.

[1] C. E. Kenneth Mees, J. Opt. Soc. Am. **21**, 753 (1931); **22**, 204 (1932); **23**, 229 (1933).

[2] L. G. S. Brooker and G. H. Keyes, *New Sensitizers for the Photography of the Infra-Red, Tetra- and Pentacarbocyanines*, J. Frank Inst., 1935.

[3] L. G. S. Brooker, F. M. Hamer and C. E. K. Mees, *Recent Advances in Sensitizers for the Photography of the Infrared*, J. Opt. Soc. Am. **23**, 216 (1933).



In the tricarbocyanines, the two heterocyclic nuclei are linked together by the seven-carbon chain, : CH.CH : CH.CH : CH.CH : CH., and it would be expected that further lengthening of this chain would give rise to cyanine dyes whose absorption bands, and hence their sensitizing bands, are situated still further out in the infra-red.

Dr. Brooker and Mr. Keyes have now been successful in preparing cyanine dyes in which the two heterocyclic nuclei are linked together by the nine-carbon chain, : CH.CH : CH.CH : C(O Acyl).CH : CH.CH : CH., and by the eleven-carbon chain, : CH.CH : CH.CH : C(O Acyl).CH : CH.CH : CH.CH : CH., the dyes containing these chains being named tetra-carbocyanines and pentacarbocyanines, respectively.

With these dyes, new emulsions of exceptional sensitivity in the far infrared have been prepared.

The Type Q sensitizing has been changed, and instead of xenocyanine (lepidine tricarbocyanine) a tetracarbocyanine is being used, with which the plates can be made far more stable and freer from fog. The position of maximum sensitivity of the new Type Q plates is the same as the old and their total sensitivity is no greater, but they can be prepared with greater ease and they are much easier to handle.

One of the new dyes gives an emulsion with a strong maximum at λ9300, the spectrum extending from λ8000 to λ10,000, with much greater sensitivity than that available with Type Q. This has been named the Type M sensitizing, and it is believed it will be very useful in practice.

Finally, a pentacarbocyanine has been made, which gives a maximum of sensitivity at λ10,900. Plates made with this dye which are known as Type Z enable the infrared to be photographed

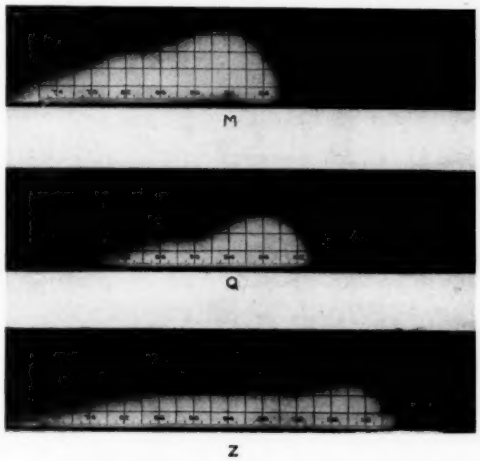


FIG. 1. Wedge spectrograms showing Types M, Q and Z sensitizings for the infrared.

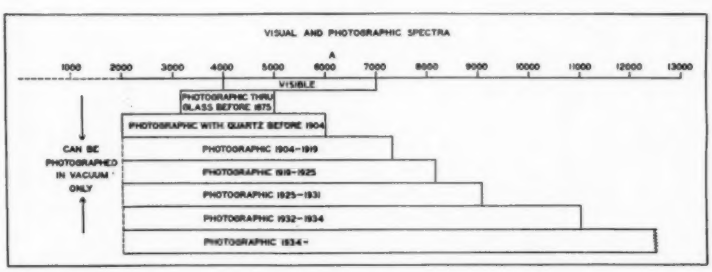


FIG. 2. Extension of the photographed spectrum.

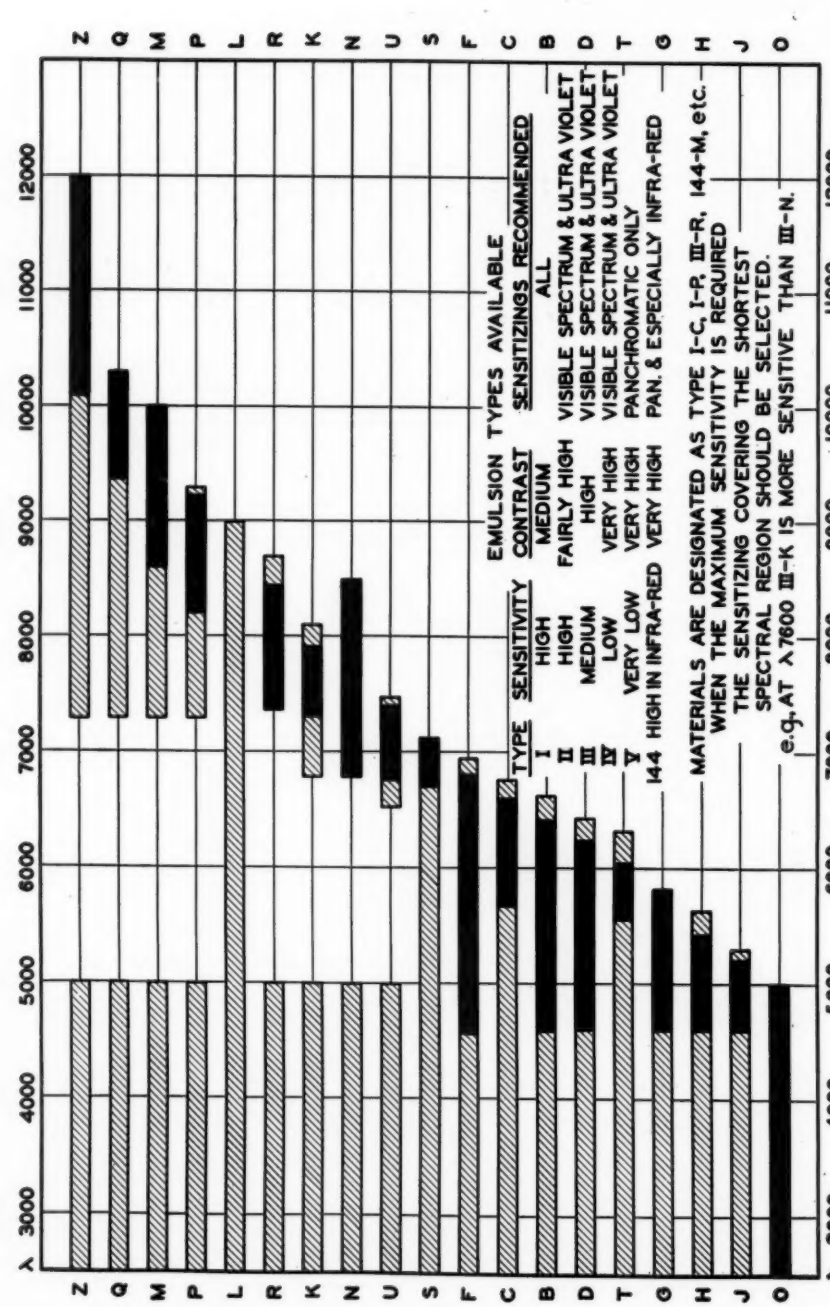

λ 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000
Z Q M P L R K N U S F C B D T G H J O
EMULSION TYPES AVAILABLE
TYPE SENSITIVITY CONTRAST SENSITIZINGS RECOMMENDED
I HIGH MEDIUM ALL
II HIGH FAIRLY HIGH VISIBLE SPECTRUM & ULTRA VIOLET
III MEDIUM HIGH VISIBLE SPECTRUM & ULTRA VIOLET
IV LOW VERY HIGH VISIBLE SPECTRUM & ULTRA VIOLET
V VERY LOW VERY HIGH PANCHROMATIC ONLY
144 HIGH IN INFRA-RED VERY HIGH PAN. & ESPECIALLY INFRA-RED
MATERIALS ARE DESIGNATED AS TYPE I-C, I-P, III-R, 144-M, etc.
WHEN THE MAXIMUM SENSITIVITY IS REQUIRED
THE SENSITIZING COVERING THE SHORTEST
SPECTRAL REGION SHOULD BE SELECTED.
e.g. AT λ 7600 III-K IS MORE SENSITIVE THAN III-N.

FIG. 3. Diagram of spectral sensitivity regions of spectroscopic plates.

some 1500A or 2000A further into the infrared than was possible with the Type Q plates. Up to the present, it is only possible to sensitize the Type I emulsion with this dye so that only I–Z plates are available. These plates have about the same quality as the previous I–Q plates. They seem to have fair stability and they do not show more fog, but they lack contrast and require great care in handling. With these plates, the mercury spectrum shows the λ11,287 line of about the same intensity as the line at λ10,142,[4] and the sharp doublets of sodium and potassium between 11,000 and 12,000 are very easy to photograph. The sensitizings of the new Types M, Q and Z plates are shown in Fig. 1.

[4] By the kindness of Mr. F. Twyman I am enabled to state that he has found Hg 11,287 to be 50 percent stronger than Hg 10,142, using a silica mercury vapor lamp and Hilger infrared spectrometer with thermopile.

The progress made in the photography of the spectrum was summarized as recently as 1933 in a diagram showing the steady extension of the photographed spectrum.[5] The recent extension made possible by the Type Z plates, justifies a revision of this diagram, which is shown in Fig. 2. In order to summarize the various spectroscopic plates available, a new chart is inserted as Fig. 3, a spare copy being placed in the Journal as a supplement. Fig. 3 shows the recommendations which the author makes for different spectral regions. In using this diagram, it should be remembered that where one sensiziting covers a shorter range of the spectrum, it is recorded because over that shorter range it will enable less exposure to be given than where a sensitizing covering a longer range is employed.

[5] Brooker, Hamer and Mees, reference 3, p. 222.

The Penetration of the Red, Green and Violet Components of Daylight into Atlantic Waters

R. H. OSTER AND G. L. CLARKE, *Woods Hole Oceanographic Institution* and the Biological Laboratories, Harvard University*

(Received November 21, 1934)

THE penetration of light into natural waters is of interest from the purely physical point of view in relation to the differential effects of dissolved and suspended substances upon the rates of absorption of the different spectral components of daylight and in relation to the heating of the water at different depths by the radiation absorbed. From the biological viewpoint the intensity of the light beneath the surface and its spectral distribution is of importance in the study of the photosynthesis of aquatic plants, the formation of Vitamin D stored in fish liver oils and the movements of photosensitive animals. Observations on the penetration of light into the sea and into lakes in connection with these problems have been undertaken in various parts of the world by Atkins and Poole[2] and others.[3, 6, 11, 17]

Certain measurements were made previously in Atlantic coastal waters by the present authors in relation to the diurnal migration of the zooplankton and the metabolism of the phytoplankton.[4, 5] Since in these observations it was possible to measure only the blue and red components of daylight, we desired to extend the work into the green and violet regions of the spectrum. Furthermore, it was proposed to make a careful comparison of different types of oceanic and coastal waters not only in respect to their general transparency but also in regard to their relative powers of absorption for different regions of the spectrum.

The observations reported in this paper were made from the *Atlantis* and the *Asterias* during the summer of 1934. Measurements were made of the red, green and violet components of daylight and compared with values obtained previously for blue and red light. Three regions characterized by distinct types of Atlantic water were investigated, namely, the Sargasso Sea, the Gulf of Maine, and the coastal areas near Woods Hole.

* Contribution No. 58.

APPARATUS AND METHODS

The photoelectric method previously described[7, 4] was used. For the measurement of the red region of the spectrum (see Fig. 1) the same vacuum caesium photoelectric cells under the Schott-Jena RG-1 glass filters and $CuCl_2$ liquid filters were employed.[5] As before, each liquid filter was cemented with Canada balsam to the inside surface of the window of its photometer. The glass color filter, however, was cemented to the under surface of the opal diffusing disk, thus lying between the opal disk and the upper surface of the photometer window. The RG-1 glass filter with its opal disk could therefore easily be removed without opening the photometer case. The space between the glass filter and the photometer window was filled with water in the case of the submarine photometer.

For the measurement of the green region of the spectrum (Fig. 1) the opal disks with the RG-1 glass filters attached were removed from the photometers containing the caesium cells and replaced by other opal disks to each of which a combination of two filters had been cemented. The filters used were Schott-Jena BG-18 and GG-11.

The measurements in the violet region of the spectrum (Fig. 1) were made with two new vacuum potassium (unsensitized) photoelectric cells specially constructed by the General Electric Company and of the same type as the caesium cells. These new potassium cells were obtained to replace the original sensitized potassium cells which were somewhat unstable. The potassium cells were used without filters and since the point of maximum spectral sensitivity of the new cells occurred farther toward the short wavelength end of the spectrum, the light measured by these cells is designated "violet" to distinguish it from the "blue" region measured by the original cells.

The three combinations of photoelectric cells and filters covered the spectrum from 3000A to

7000A. Each combination is sensitive to a band of wavelengths roughly 1000A in width. Since each of the bands has a relatively sharp cut-off at its limits, the region designated as "red" may be taken as extending from 6000A to 7000A, "green" from 4900A to 6200A, and "violet" from 3100A to 4500A. A gap exists between the "green" and "violet" but the measurements previously made in the "blue" region (3460A to 5260A) have provided information on the penetration of light in this part of the spectrum.

Standardization against the 1000-watt standard lamp was carried out as before. The irradiation in microwatts per square centimeter represented by an emission of one microampere in each of the three deck photometers is as follows: Red, 1340; green, 1885; violet, 181. The sea photometers were calibrated against the deck photometers at the time of use as previously described.[4] All values below the surface have been corrected for "external reflection" and "internal reflection" by multiplying by the factor 1.09.[2] Checks made before and after each series of observations with the portable test lamp showed the photometers to be satisfactorily stable in their emissions. The emission of the deck photometer containing the new potassium cell did not vary by more than 3 percent (except for one case of 6 percent) during the course of the summer's work.

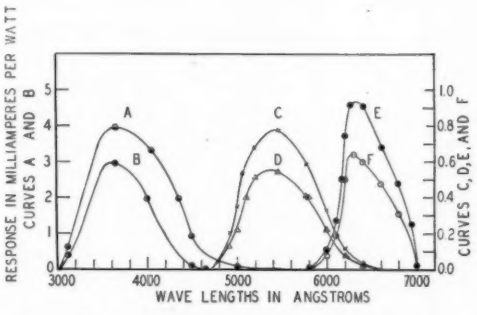


FIG. 1. Spectro-sensitivity curves of photoelectric cells with color filters:

A—Violet: General Electric Co. vacuum potassium cell No. 34283. Used in Sea Photometer No. 1b.
B—Violet: General Electric Co. vacuum potassium cell No. 34284. Used in Deck Photometer No. 1b.
C—Green: G. E. Co. Type PJ-14 caesium on caesium oxide cell No. 31613 with Schott and Gen. Jena filters BG-18 and GG-11 and $CuCl_2$ liquid filter. Used in Sea Photometer No. 2c.
D—Green: G. E. Co. Type PJ-14 cell No. 31797 with same type of filter combination as in C. Used in Deck Photometer No. 2c.
E—Red: G. E. Co. Type PJ-14 cell No. 31613 with Schott and Gen. Jena Type RG-1 glass filter and $CuCl_2$ liquid filter. Used in Sea Photometer No. 2b.
F—Red: G. E. Co. Type PJ-14 cell No. 31797 with same type of color filter combination as in E. Used in Deck Photometer No. 2b.

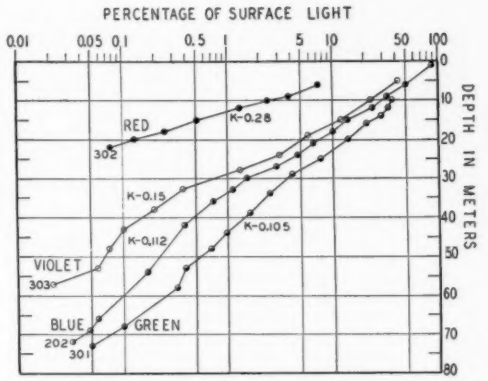


FIG. 2. Relation between depth and irradiation expressed as a percentage of the light just over the surface (logarithmic scale). Series number indicated at end of each curve. Observations made in the deep basin of the Gulf of Maine.

Series 301, 302, 303 at Station 2237. July 17, 1934,
Series 202 at Station 1722. July 15, 1933.

OBSERVATIONS

The observations made on the penetration of red, green, and violet light are summarized in Table I. The curves presented in Figs. 2–7 are grouped according to locality and show the percentage of the surface light reaching the various depths. Comparisons may therefore readily be made on the basis either of color or of type of water. In certain cases curves from previous observations representing the penetration of blue light have been added to the figures to show the relation of this component to the others.

In the deep basin of the Gulf of Maine (Fig. 2) the penetration of the different spectral components of daylight varied from that of the red (transmissive exponent, $k=0.28$)* to that of the green ($k=0.105$). Since the value obtained for the transmission of red light was nearly the

* The transmissive exponent, k ("absorption coefficient," cf. Sawyer, 1931) is defined by the following formula: $I/I_0=e^{-kL}$ where L is the thickness of the water layer (in meters) in which the intensity is reduced from I_0 to I.

TABLE I. *Summary of observations.*

Station	2237	2238	2243	2245	2246	Woods Hole Harbor	Off Gay Head	Vineyard Sound	Buzzards Bay
Latitude N.	42°08′	40°48′	35°52′	37°35′	39°27′	41°31′	41°20′	41°30′	41°33′
Longitude W.	69°04′	68°40′	65°30′	68°44′	69°43′	70°40′	70°57′	70°36′	70°42′25″
Depth of water (meters)	165	60	5011	4485	2380	20	30	24	16
Date, 1934	July 17	July 18	July 22	July 24	July 25	Aug. 9[1]	Aug. 17[2]	Aug. 21[3]	Aug. 28[4]
Red Light (6000A–7000A) Photometer No. 2b									
Series No.	302	305	309	312	313	317	320	323	326
Local sun time (24 hr. scale)	1215–1248	1147–1230	1210–1350	1413–1500	950–1035	1255–1340	1228–1328	1307–1347	1036–1111
Av. altitude of sun	68	70	70	52	61	59	60	55	55
Av. trans. exponent k over depth studied	0.28	0.35	0.082	0.13	0.23	0.56	0.37	0.46	0.50
Range of irrad. on deck during series, microwatts/cm²	13,500–13,300	14,100–4,700	13,800–11,800	10,200–8,000	6,500–9,200	14,000–11,100	12,700–11,400	11,200–10,400	8,200–10,700
Green Light (4900A–6200A) Photometer No. 2c									
Series No.	301	304	307	311	314	316	321	322	325
Local sun time (24 hr. scale)	1002–1135	1045–1145	1029–1205	1225–1345	1049–1200	1010–1135	1333–1438	1108–1202	0926–1011
Av. altitude of sun	64	68	68	67	69	61	51	60	47
Av. transmissive exponent k over depth studied	0.11	0.13	0.050	0.049	0.074	0.30	0.16	0.20	0.25
Range of irrad. on deck during series, microwatts/cm²	18,600–20,400	18,000–21,000	25,400–8,700	23,400–21,100	10,000–19,700	19,300–15,900	17,600–15,200	16,800–16,200	10,500–13,800
Violet Light (3100A–4500A) Photometer No. 1b									
Series No.	303	306	308	310	315	318	319	324	327
Local sun time (24 hr. scale)	1300–1346	1300–1340	1310–1435	1002–1155	1212–1320	1446–1503	1113–1158	1412–1502	1215–1251
Av. altitude of sun	63	64	61	67	68	45	62	45	57
Av. trans. exponent k over depth studied	0.15	0.17	0.053	0.048	0.098	0.55	0.25	0.36	0.40
Range of irrad. on deck, microwatts/cm²	11,800–10,150	12,000–10,250	4,900–7,900	10,700–12,500	11,200–4,900	9,200–7,700	10,900–10,200	8,740–7,400	2,200–4,900

[1] Tide turned to run from Vineyard Sound at 0936.
[2] Tide turned to flow east at 0955.
[3] Tide turned to flow east at 1417.
[4] Tide turned to flow NE at 1649.

same as that obtained in this region the year previous, it seemed permissible to compare the curve obtained previously for blue light with the present curves for the other components. Thus the transparency of Gulf of Maine water appears to be about the same for the blue and green components of daylight. Violet light penetrates only slightly less well, whereas red light is absorbed about twice as quickly. The hydrographic observations made at this station (Table II) show that an abrupt change in temperature and in salinity occurred in the water layers between 10 and 25 meters. Although the curves are more or less irregular, no one of them shows changes of slope corresponding to this pronounced hydrographic condition, nor is there a consistent change in direction of all the curves at any one depth.

The transmission of light in the waters on Georges Bank is somewhat lower than in the deep basin of the Gulf. Here the green component has the highest power of penetration, blue and violet slightly lower, and red the lowest. The value of the transmissive exponent for red light is the same as that obtained in this region the year before. The curves are all remarkably straight, indicating constant rates of transmission in all strata for the different spectral components. This constancy is consistent with the homogeneity of the water at this station as revealed by the hydrographic measurements (Table II). The water has been thoroughly stirred from top to bottom and whatever elements are responsible for the rate of light absorption have been evenly distributed throughout the water mass.

The observations in the Sargasso Sea region were made first at a point about 200 miles north of Bermuda (Station 2243), a location which was well clear of the Gulf Stream, and second at a point 200 miles northwest of this (Station 2245) in the middle of the Gulf Stream. Since the transparency of the water at these two stations was approximately the same, only one curve for each region of the spectrum has been presented (Fig. 4). The values obtained show that the water in this area was more transparent to all wavelengths than was the case in any of the other areas investigated. In view of the well-known uniformity of the water in different parts

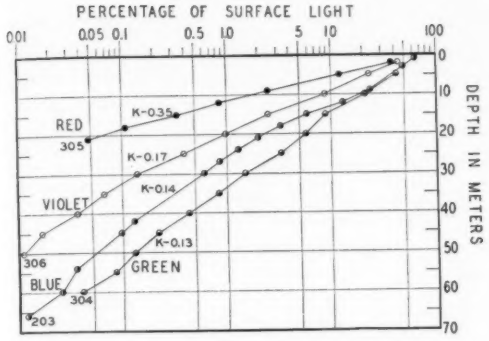


FIG. 3. Observations made on Georges Bank.
Series 304, 305, 306 at Station 2238. July 18, 1934,
Series 203 at Station 1723. July 17, 1933.

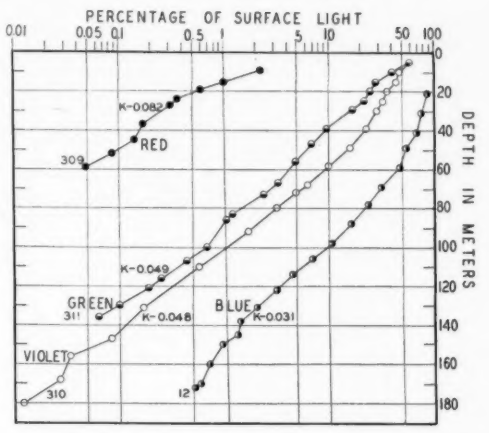


FIG. 4. Observations made in the Sargasso Sea and Gulf Stream.
Series 309 at Station 2243 on July 22, 1934,
Series 310 and 311 at Station 2245 on July 24, 1934,
Series 12 at Station 1041 on August 15, 1931.

of the Sargasso Sea it seems permissible to compare with the present observations the measurements of blue light made three years previously at Station 1041, 600 miles east of Station 2243. Such a comparison indicates that in the Sargasso Sea the blue component of daylight penetrates considerably more effectively than either the green or the violet and almost three times as effectively as the red. It is interesting to note that the upper part of the curve for violet light is significantly steeper than the lower part just as is the case for the curve for blue light, as was pointed out previously.[4] In the curves for green and red light the reverse is true, lower transmission being indicated in the upper strata than in the deeper. The other curves (not presented here) for the penetration of violet, green, and red light in the Sargasso Sea region show, respectively, the same changes of slope. The upper water layers appear to differ from the underlying strata in some feature which affects the rays of short wavelength and those of long wavelength in opposite ways.

TABLE II. *Hydrographic observations.*

Station 2237			Station 2243 (Data from station 2244 a few miles distant)		
Depth (m)	Temp. °C	Salinity 0/00	Depth (m)	Temp. °C	Salinity 0/00
1	19.13	32.01	12	25.64	36.26
10	18.91	.01	35	25.30	.34
15	11.37	.23	47	23.48	.39
20	9.16	.38	59	25.66	.28
25	5.91	.61	71	25.61	.31
30	4.86	.67	83	24.55	.38
35	4.57	.73	94	22.88	.46
40	3.96	.75	100	21.30	.48
50	3.82	.84	199	19.35	.54
60	3.71	.90	Station 2245		
80	3.37	.98	48	27.01	36.03
100	3.81	33.13	95	24.16	.51
Station 2238			143	21.34	.61
1	11.49	32.69	190	19.63	.57
10	11.23	.70	Station 2246		
20	10.81	.71	10	24.91	34.99
30	10.61	.71	29	19.62	35.81
40	10.53	.71	38	18.00	.99
50	10.19	.73	86	14.02	.70
			143	11.52	.39
			190	10.61	.35

Measurements made in the "Slope Water", between the Continental Shelf and the Gulf Stream at a point 100 miles south of Nantucket Shoals (Station 2246), revealed a striking situation in regard to the optical properties of the water strata in this region (Fig. 5). Considering first the curve for violet light, it is seen that the upper 20 meters of water were highly transparent, but that from 20 to 39 meters the penetration of violet light was greatly reduced, the transmission being only about one-fourth that found above 20 meters. Below 39 meters the transparency of the water suddenly increased again, and from this depth down to the end of the series the water was almost as clear as in the surface stratum. The abrupt change in transparency was noticed at the time the observations were being made and the measurements were

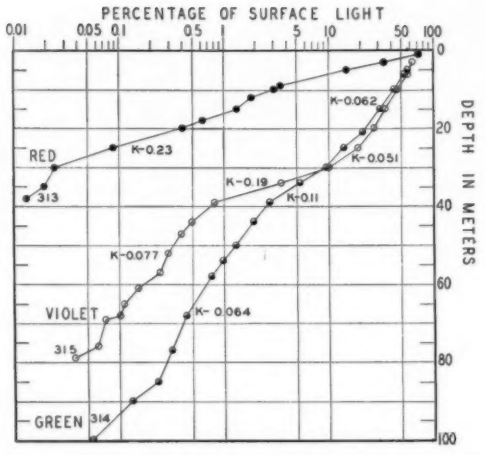


FIG. 5. Observations made in the "Slope Water" between the Gulf Stream and the Continental Shelf. Series 313, 314 and 315 at Station 2246 on July 25, 1934.

twice repeated in the zone from 30 to 39 meters. The change in values is far greater than could be accounted for by an error of measurement. The curve for green light shows exactly the same changes of slope, although the reduction of transmission in the stratum from 21 to 39 meters is not as great. In the case of the red component the curve does not show a break in the vicinity of 20 meters. Although an increase in transparency is indicated beginning at 30 meters, this may not be significant since the measurements at the bottom end of the series are ordinarily somewhat less reliable than the others. Temperature measurements made with the "oceanograph" to a depth of 100 meters revealed the presence of a sharp thermocline at this station extending from 20 to 40 meters.* Above 20 meters and below 40 meters the temperatures were very nearly constant. The salinity reached a maximum at 38 meters (Table II). It is evident, then, that in the stratum from 20 to 40 meters the density of the water was increasing at a rapid rate. If particulate matter were present which was heavier than the surface water but lighter than the deeper water it would reach an equilibrium in this intermediate zone. Thus a "cloud" of particles would be suspended at the thermocline which might account for the decreased transparency.[10] Since red light apparently does not suffer a corresponding diminution in this stratum, we would have to assume that the suspended material was highly selective. In the Gulf of Maine where a thermocline was similarly encountered no changes in transparency were observed which clearly corresponded to the change in density.

In coastal waters the intensity of all wavelengths is much reduced. Of the areas studied in the Woods Hole region the waters off Gay Head were the most transparent (Fig. 6). The same value for the transmissive exponent for red light was obtained in the present investigation as in the previous observation. The transmission for violet light was found to be nearly the same as that observed for blue light the year before. However, the penetration of green light in this region was nearly twice as great as that of the other components of daylight.

In Vineyard Sound where the water is thoroughly stirred by strong tidal currents, the rate of light absorption is very nearly constant at all depths as is attested by the fact that the curves approach straight lines (Fig. 7). In this locality the green region of the spectrum was found to penetrate much the most readily. The transmission of red light was somewhat greater in the present case than previously, but comparisons among observations made near shore on different occasions can be made only with caution since local conditions fluctuate so profoundly.

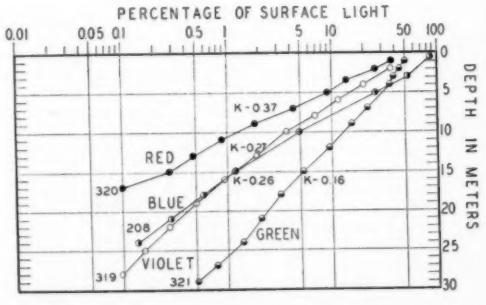


FIG. 6. Observations made off Gay Head. Series 319, 320 and 321 on August 17, 1934, Series 208 on September 2, 1933.

* I am indebted to Professor C. G. Rossby and Mr. R. T. Montgomery of the Woods Hole Oceanographic Institution for this information.

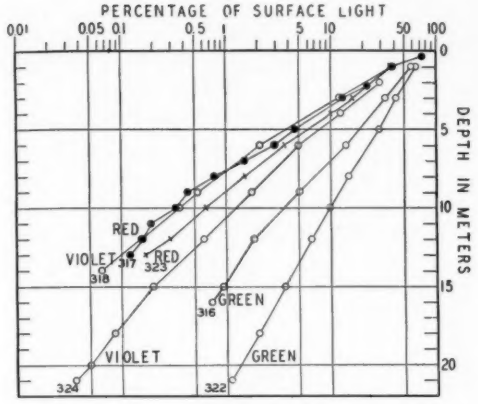


FIG. 7. Observations made in Vineyard Sound. Series 322, 323, 324 on August 21, 1934. Observations made in Woods Hole Harbor. Series 316, 317, 318 on August 9, 1934.

However, since the values for the transmissive exponents for violet light obtained in the present investigation and for blue light obtained the year before were identical, it seems probable that the water in Vineyard Sound is about equally transparent to these two components of daylight.

The penetration of light into Woods Hole Harbor was the lowest observed (Fig. 7), although the waters of Buzzards Bay were only slightly more transparent (see Table I). In Woods Hole Harbor the rates of absorption of the red and violet components were practically the same and the value obtained two years before for blue light was only slightly lower. Here, as in the other coastal areas, the water is most transparent to the green region of the spectrum.

DISCUSSION

The localities where measurements were made may be arranged in order of decreasing transparency as follows:

Gulf Stream
Sargasso Sea
"Slope Water"
Gulf of Maine
Georges Banks
Off Gay Head
Vineyard Sound
Buzzards Bay
Woods Hole Harbor.

The sequence is the same for all three of the spectral regions considered (with one exception: The transparency for red light is greater in the Sargasso Sea than in the Gulf Stream) and also for blue light.[5] However, the amount of reduction of each of the spectral components is not the same, as is revealed by a comparison of the ratios of the highest to the lowest values of the transmissive exponents: Red, $0.56/0.082=6.8$; green, $0.30/0.049=6.1$; violet, $0.55/0.048=11.5$; blue, $0.49/0.031=15.8$.

The intensity of the blue and violet components is diminished much more extensively than that of the longer wavelengths. The penetration of green light has been reduced least of all. It must be remembered, however, that the transmission of red light was found everywhere to be the lowest and that the rate of penetration of violet and especially of blue light exceeds that of green in the clearest ocean waters. In other words, the high irradiation present in the Sargasso Sea is due in large measure to the great increase in the penetration of the shorter wavelengths.

As a corollary to the foregoing conclusions, it may be pointed out that as general transparency decreases, the differences in the penetration of the various components of daylight become less. The ratios of the transmissive exponents for blue and violet light to that for red light vary from about one-third in the clearest ocean water to nearly unity in areas close to shore. The ratios of green to red light are more nearly constant, varying only from one-third to one-half. However, it is important to note that the fluctuations in the relative transparency of the water to different regions of the spectrum are of minor extent compared to the differences in general transparency of various parts of the sea. The waters of the Sargasso Sea are 2 to 4 times more transparent than the Gulf of Maine and 6 to 16 times more transparent than Woods Hole Harbor.

The measurements of the penetration of the blue and, for coastal waters, the red components of daylight have already been discussed in relation to the observations of other investigators.[4, 5] Comparison of light penetration in parts of the spectrum not near the region of minimum absorption are difficult because of the

great variation resulting from small differences in the wavelengths included in the measurements. It is not surprising, therefore, that our values for violet differ considerably from those of Atkins and Poole[2] who report an average $k=0.39$ at 3600A for Station E 1 and from those of Grein[8] which range from $k=0.092$ to $k=0.011$ for "blue-violet" in the Mediterranean. The reliability of Grein's measurements is extremely doubtful because of the great irregularities in the values obtained in all parts of the spectrum.[1] The lowest average value for violet light obtained in the present investigation was $k=0.048$ ($k=0.030$ for the upper 50 meters). Since in the case of distilled water values as low as this are found only for wavelengths longer than 4100A,[13] it is evident that the energy reaching the photo-cell was near the upper limit of the spectral region to which the photometer was sensitive.[17]

The transmission of red light in the Sargasso Sea appears to be higher than in any other region of the ocean. The minimum value for the average transmissive exponent, $k=0.082$, is lower than any hitherto reported except for one doubtful value of Grein's. This value is slightly lower than that found by Sawyer for distilled water at wavelength 5900A. This suggests not only that the energy reaching the photo-cell was at wavelengths near the lower spectral limit of transmission of the red filter but also that a very low concentration of scattering media existed in the Sargasso Sea water.

In respect to the transparency of the water to the green component of daylight the Gulf of Maine appears from our observations to be similar to Whitsand Bay.[2] In the English Channel (Station E 1) the transmission of green light is slightly lower, and 28 miles off Vancouver Island[17] it is slightly higher than in the Gulf. The coastal waters near Woods Hole correspond rather closely to the San Juan Archipelago[16] and to Baltic Sea waters.[12] The minimum value for the transmissive exponent in the green region, $k=0.049$, obtained in the Sargasso Sea, apparently is the lowest which has been reported, again with the exception of questionable values from Grein's observations. Since the value of the exponent for distilled water is $k=0.024$ at wavelength 5400A,[13] there is no question in the case of green light of the transparency in the Sargasso Sea approaching or surpassing that of distilled water as in the case of the violet, the red, and the blue[4] components. Since the maximum spectral sensitivity of the human eye falls within the range of our "green," it seems permissible to make a rough comparison between these measurements and two interesting observations using visual photometers. From the data obtained by Beebe off Bermuda and plotted by Hulburt[9] the average transmissive exponent from 15 to 150 meters has been calculated and found to be $k=0.047$. Stephenson[14] obtained a value of $\gamma=0.0075$ ($k=0.057$) for 7 to 20 meters from a submarine off Coronados Island, California.

The differences in relative penetration of the green and blue components in the various localites investigated by us may be compared with those observed in other regions. The ratio of the transmissive exponent for green to that for blue light for the water off Gay Head was found to be 0.62 and similar low ratios were reported from the San Juan Archipelago and the inside Alaskan passage.[15] The transmission of green and of blue light was about equal in the Gulf of Maine as was also the case in Whitsand Bay. In the English Channel (Station E 1) and off Vancouver Island the water was reported to be slightly more transparent to the blue component. In the Sargasso Sea the transmission of blue light was considerably greater than the green, the ratio of the exponents rising to 1.6. Our observations are therefore consistent with those of other investigators and confirm the general idea that green light is the most penetrating region of the spectrum for coastal waters and blue light for the clearest ocean waters.

The authors are indebted to Mr. W. Norris Tuttle of the General Radio Company, Cambridge, Massachusetts, for valuable advice leading to the improvement of the amplifier for the potentiometer.

Summary

(1) Photoelectric measurements of the penetration of the red, green and violet components of daylight into the sea were made in the Sargasso Sea, in the Gulf of Maine and in coastal areas near Woods Hole. Measurements

made previously in the blue region of the spectrum are compared with the present observations. The same method and apparatus were used as previously, with the addition of two vacuum potassium (unsensitized) photo-cells and two sets of color filters.

(2) In the Gulf of Maine green and blue light penetrate equally well, violet light slightly less well, and red light only half as well. The water in the Sargasso Sea is from 2 to 4 times more transparent, being most transparent to blue, somewhat less so to green and violet, and considerably less so to red light. In the "Slope Water" beyond the continental shelf a stratum of relatively opaque water was discovered which corresponds in depth to a zone of rapidly increasing density. The waters off Gay Head, in Vineyard Sound, in Buzzards Bay and in Woods Hole Harbor were characterized by progressively decreasing transparency in the order named. In these localities the water was twice as transparent to green as to the other parts of the spectrum.

(3) The Sargasso Sea is the most transparent part of the ocean where quantitative measurements have been made. Here minimum average values of the transmissive exponent were obtained as follows: red, $k=0.082$; green, $k=0.049$; violet, $k=0.048$.

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Optical Society of America, Incorporated

Notice of Election of Officers

In accordance with Article III, Section 6, of the By-laws of the Optical Society of America the following officers and directors are to be elected at or before the Annual Meeting in October, 1935:

President, Vice President } for a term of two years

2 Members-at-large of the Board of Directors for a term of four years

The present officers are:

		Term expires at annual meeting in:
President	—W. B. Rayton	1935
Vice President	—Arthur C. Hardy	1935
Secretary	—L. B. Tuckerman	1937
Treasurer	—Henry F. Kurtz	1937
Past President	—E. C. Crittenden	1935
Editor	—F. K. Richtmyer (elected by Directors)	1936

Directors-at-large:

A. H. Compton H. E. Ives C. W. Keuffel	1937
R. C. Gibbs G. B. Pegram	1935

In accordance with the By-laws, Article III, Section 4, R. C. Gibbs and G. B. Pegram are not eligible for reelection:

"No member-at-large of the board of directors shall be eligible for reelection."

The following Committee on Nominations has been appointed and confirmed in accordance with Article III, Section 6, of the By-laws:

E. C. Crittenden, Chairman,
National Bureau of Standards,
Washington, D. C.

J. P. C. Southall,
Columbia University,
1118 Physics Laboratories,
New York, New York

P. I. Wold,
Union College,
Schenectady, New York

R. B. Wilsey,
Research Laboratories,
Eastman Kodak Co.,
Rochester, New York

R. T. Birge,
Le Conte Hall,
University of California,
Berkeley, California

It will be the duty of this committee to make nominations for the above-mentioned election. The Committee report is to be made not later than July 15, 1935.

Although, after the committee has made its report, an opportunity will be given for additional nominations by petition, members are urged, as soon as possible, to suggest names which should be considered by the committee. Suggestions may be sent to the Chairman or any other member of the Committee. Only regular and honorary members are eligible to election.

A membership list was published in the J.O.S.A. **21,** 449–484 (1931). Later transfers to regular membership were given in the Secretary's Annual Reports published in the J.O.S.A. **22,** 237 (1932); **23,** 225 (1933); **24,** 309 (1934); **25,** 43 (1935).

SIGNED

L. B. Tuckerman, *Secretary.*